2. LED OPTICS

2.1. Introduction

Optics is the branch of physics which involves the behavior and properties of light, including its interactions with matter and the construction of instruments that use or detect it. Luminaire is a device that changes light distribution of a light source, diffuses the light or eventually changes its spectral composition. This goal is reached by luminous active parts of luminaire (reflector, diffuser, lens, etc.) and auxiliary parts (socket, leads, starter, ballast, etc.) that are designed and constructed for specific light sources. Luminaire is also equipped with parts that are used for fixation, protection of a light source and feeder.

Optical part
The main function of the optical part is to change the distribution of luminous flux intensity from source(s) and/or diffuse light, eventually to change its spectral composition. Different geometries of optical parts create different light intensity distribution curves (LIDC).

Optical parts serve to:
• Change the distribution, regulation or distraction of luminous flux
• Reduce the brightness of the luminaire at the angle where can be perceived by an observer – Glare-limiting
• Change the spectrum of the light emitted by a light source – Filtration

Light intensity distribution curve - LIDC
Measured values of luminous intensity of point-like light source in all directions are applied to space from the light source as the radius-vectors. Linking these endpoints we get photometric luminance surface. In calculations, it is usually sufficient to know only certain cuts of this 3D surface, mainly in cutting planes passing through the light source. In this manner, we get lines (lighting curves) in polar coordinates (see Figure 2.1.2). Values of luminous intensities shown in catalogue diagrams are unified on luminous flux of a 1000-lm light source in order to obtain lighting curves of luminaires which are independent on measured luminous flux of used light sources. Illuminated spaces require different shapes of LIDCs (see Figure 2.1.3 and Figure 2.1.4) to achieve standards required by particular application or visual task. There are numerous types of lighting fixtures with different optical parts to fulfil these needs.

LIDCs are usually indicated in certain planes where its intersection passes through the centre of a luminaire or a light source. The most often used beam plane is C-γ, whose axis is vertical to the main light emitting area of the luminaire.
Efficiency of optical part – (LOR - Luminaire Output Ratio)
Is defined as follows:

\[ \text{LOR} = \frac{\Phi_{\text{Luminaire}}}{\sum_i \Phi_{\text{Source}}} \times 100 \% \]

The efficiency of the optical part is equal to ratio between the luminaire luminous flux \( \Phi_{\text{Luminaire}} \) and the sum of luminous fluxes of all light sources within the luminaire.

### 2.2. Reflector

Reflector is an optical part that regulates luminous flux from the light source by reflection from the reflector material – a mirror reflection, a diffuse reflection, and a mixed reflection (also see Figure 2.5.1). Reflectors are basically divided into two groups: first group includes conic reflectors of four basic geometries – elliptical, zonal, hyperbolic, and parabolic (Figure 2.2.1); second group includes non-conic reflectors, such as square or asymmetric ones of the same basic geometries of reflection surfaces.

**Elliptical reflector** – if the light source is placed in focus of reflector which is formed as a part of an ellipse, then the light beams are reflected into the second focus of an imaginary ellipse. Such reflectors are used in applications which need medium-wide to wide LIDC.

**Zonal reflector** – this type of reflector uses out-centred part of the different circles connected with their ends. Its advantage is precise direction of the light to intended location, but reflector geometry is sensitive to production tolerances.

**Hyperbolic reflector** – creates medium-wide to wide LIDC.

**Parabolic reflector** – creates narrow LIDC. It is used for applications where it is ask for high levels of illumination for a relatively small area.

**Facet reflector** – reflector consists of large number of small surfaces (facets) with different angles of rotation, with respect to the reflector focus, which ensures better distribution of luminous flux to the desired direction.
**Reflector shielding angle**

Shielding angles denote the degree-of-shield of the light source by a reflector within luminaire. It is the angle between the horizontal plane and the line which links the edge of the reflector and the endpoint of given light source (see Figure 2.2.4), and it is defined by following equation:

$$\delta = \arctg \frac{h}{R+r}$$

- $h$ – distance of light emitting from surface of given light source from the exit (horizontal) plane of the reflector
- $R$ – front radius of the reflector
- $r$ – radius of the light source

Figure 2.2.5 shows endpoint locations of various light sources. For example, clear incandescent bulb has endpoint located at the end of filament with respect to the observer.

**2.3. Diffuser**

Diffuser directs the light by diffuse-scattering through its material. Diffuse light is also obtained by making light to reflect diffusely from a white surface. Based on diffusion mechanism diffusers are divided into the following types: Opal, Gaussian, and Prismatic diffuser (Figure 2.3.1).

Diffuser with evenly scattered penetration (Opal) diffuses luminous flux from light source evenly to all directions thus does not create an image of the light source. Diffusers with mixed penetration (Gaussian or Prismatic) change the distribution of luminous flux preferably to certain directions thus both do not create an image of the light source and shape LIDC.

- **Opal diffuser** – creates cosine LIDC by scattering of a light on microparticles which are evenly distributed in basic diffuser material.
- **Gaussian diffuser** – creates a Gaussian-like LIDC (see Figure 2.3.2). Scattering is provided by the fine structure on surface resembling to sandblasted surface on which light beams are diffused into various directions.
Prismatic respectively micro-prismatic diffuser – basically these are refractors. Geometric structures such as pyramids, hexagons, spherical domes, and triangular ridges create requested LIDC using the refraction law. They are used in luminaires where high lighting quality is requested (UGR – Unified Glare Ratio; L_{avg} – average luminance of the luminaire).

Figure 2.3.3: Examples of the most used microprismatic diffusers.

Linear 115° prism

Linear 90° prism

Special microprismatic shape

Square pyramidal prism

Triangular pyramidal structure

Ray splitting effect with a laser beam (schematic)
2.4. Lens

Lens is an optical device with perfect or approximate axial symmetry which transmits and refracts light, converging or diverging the beam. A simple lens consists of a single optical element. A compound lens is an array of simple lenses (elements) with a common axis. The use of multiple elements allows for more optical aberrations to be corrected than is possible with a single element. Lenses are typically made from glass or transparent plastic.

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2.5. Materials for optical parts

Various optical parts need various optical materials. Aluminium with various types of finish and powder-coated metal sheets are used for reflectors. Clear polycarbonate (PC), polystyrene, and Polymethylmethacrylate (PMMA) are used for micro-prismatic diffusers and lenses.

Materials for reflective optics – with its various characteristics are available in order to achieve different types of reflection. There are three basic types of reflection: mirror, diffuse and mixed reflection. Difference between types of reflection is in the proportion of mirror and diffuse part of reflection.
Aluminium – it is the most common material for high quality reflectors thanks to its excellent reflectance. Anodized aluminium, glazed aluminium, and aluminium sheets covered with several layers of silver are also used to reach higher reflectivity and resistance against scratches.

Surface-treated sheet steel – white powder coating in various shades and structures is applied to sheet steel to achieve required reflection. If highly efficient Lambertian reflection is needed, a special material (WhiteOptics97) is applied to sheet steel.

Materials for refractive optics
- **PC** – is easily mouldable and thermo-formable. It has index of refraction equal to 1.584.
- **PMMA** – is transparent for infrared light within the range from 2.8 to 25 micrometre, and opaque for radiation shorter than 300 nm (UV radiation). Index of refraction = 1.49.